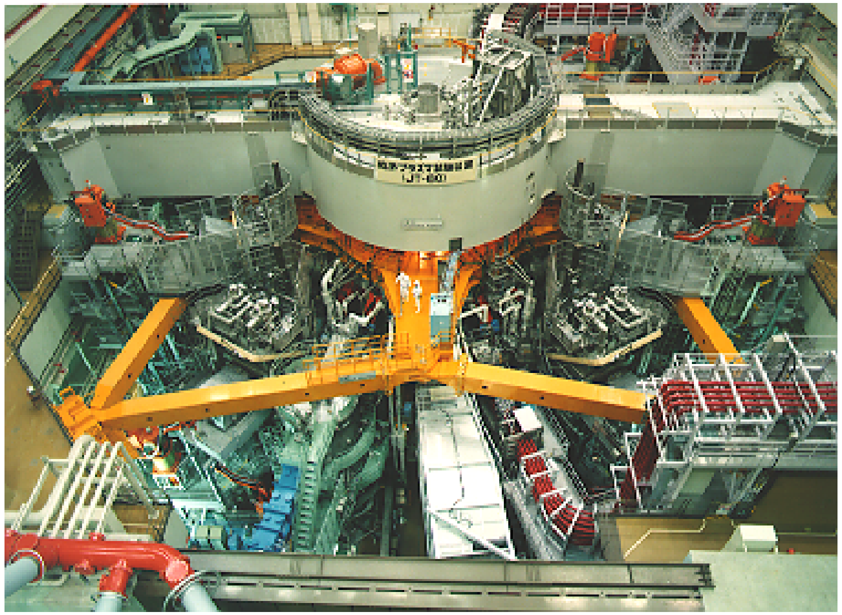
O-1.1A/P-1.85

Transport study in reactor-relevant regime on JT-60U towards advanced steady-state tokamak operation



H. Takenaga and
the JT-60 Team

Japan Atomic Energy Research Institute

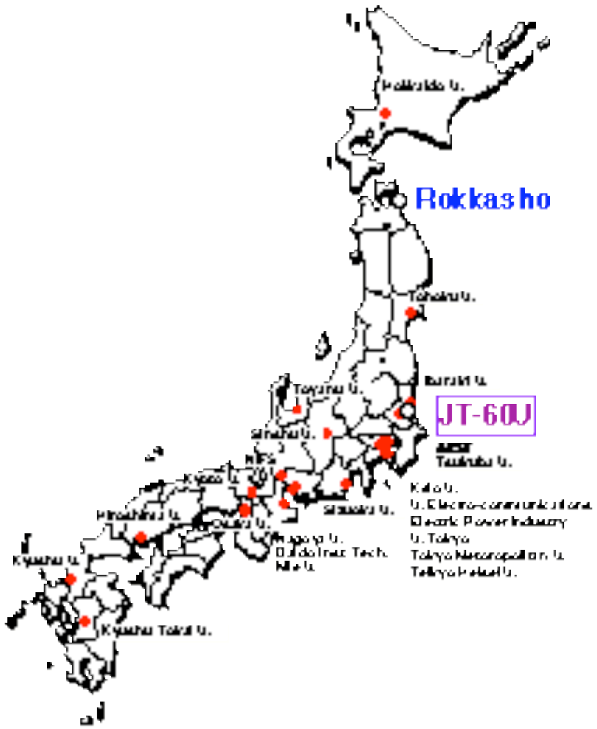
30th EPS Conference on Controlled Fusion and Plasma Physics
St Petersburg, Russia, July 7-11 2003

Enhanced collaboration with domestic and foreign universities/laboratories

JT-60U

- Many collaborators from domestic and foreign universities and laboratories contribute to the JT-60 program.

In JAPAN



From abroad

ASIPP(China), Ecole Polytech. (Switzerland), EFDA-JET (EU), GA (USA), Ioffe Inst. (RF), KBSI(Korea), KFA Juelich (Germany), Kurchatov Inst. (RF), LANL (USA), MPI-Garching (Germany), MIT (USA), ORNL (USA), PPPL (USA), SWIP (China),TRINITI(RF), U. Stractclyde (UK)

Introduction

JT-60U

- **ITER Physics R&D**
- **Advanced Tokamak Concepts for ITER & DEMO**
  - **High integrated performance;**

    - high values of β_N, HH_{y2}, f_{BS}, f_{CD}, n/n_{GW}, fuel purity, P_{rad}/P_{abs}

High β_p mode plasma **(weak positive shear)** **Reversed shear plasma**	**)**	**with internal transport barrier (ITB)**

  - **Dominant electron heating (T_e>T_i) and small central fueling;**

    - T_e ITB formation

    - Heat and particle (including impurity) transport

    Sustainment/degradation of ITB and confinement ?

    Heavy impurity accumulation ?

Development of ECRF (110 GHz) and N-NB systems

ECRF : 3 MW for 2.7 s (4 units of gyrotron)

N-NB : 6.2 MW for 1.7 s (381 keV)

⇨ **Extension of research area towards reactor-relevant regime**

OUTLINE

- T_e ITB formation condition under dominant electron heating by ECRF

- Heat and particle transport in the ITB region under dominant electron heating / small central fueling by ECRF
  - Reversed shear plasma
  - Weak positive shear plasma

- Summary and Future plan

Strong T_e ITB is formed without T_i ITB in RS plasma.

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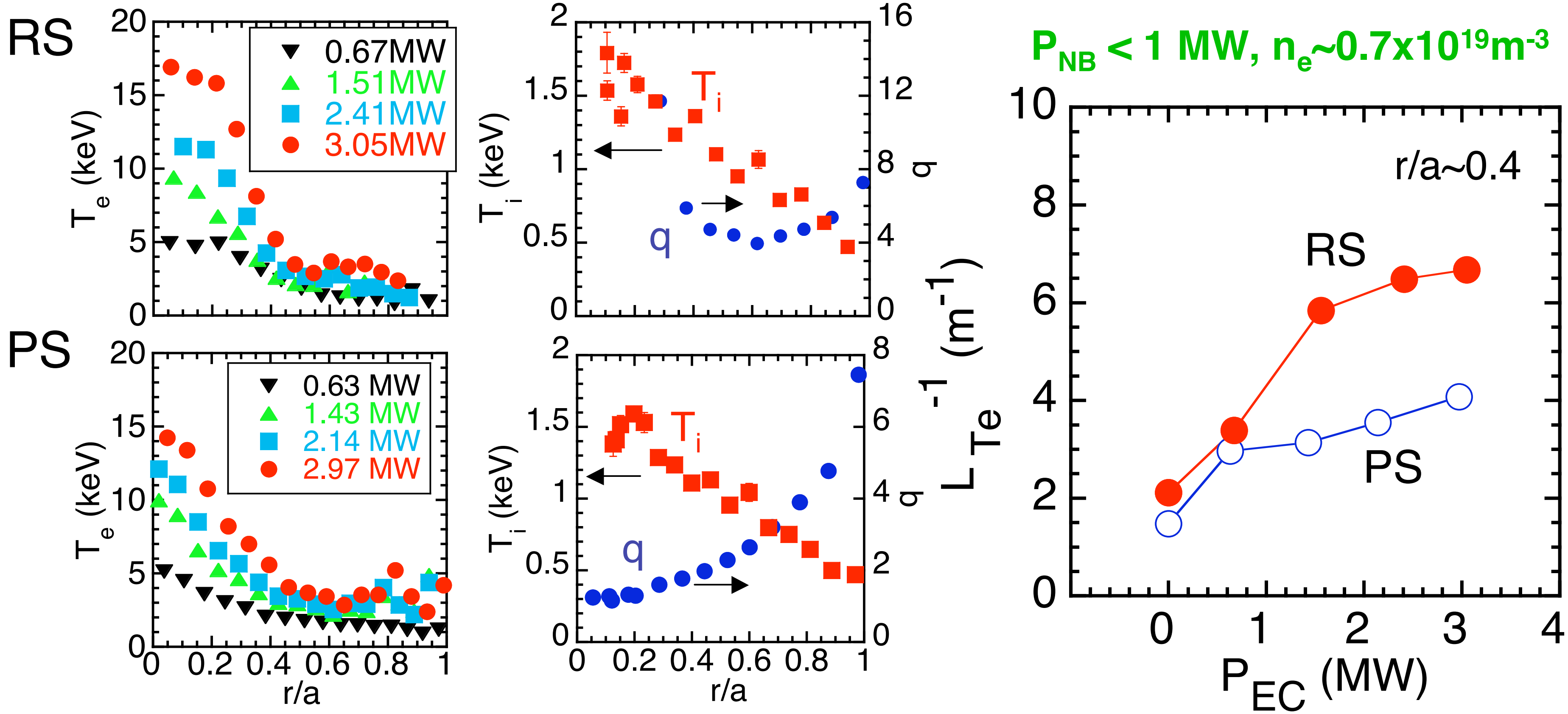
- **T_e ITB is important to improve confinement in ITER/DEMO, where T_e is expected to be higher than T_i.**
- **With no/low P-NB power, strong T_e ITB is formed in RS plasma (P_{EC}~ 1 MW) but not formed in PS plasma (P_{EC} up to 3 MW).**



Strong T_e ITB is formed with T_i ITB in PS plasma.

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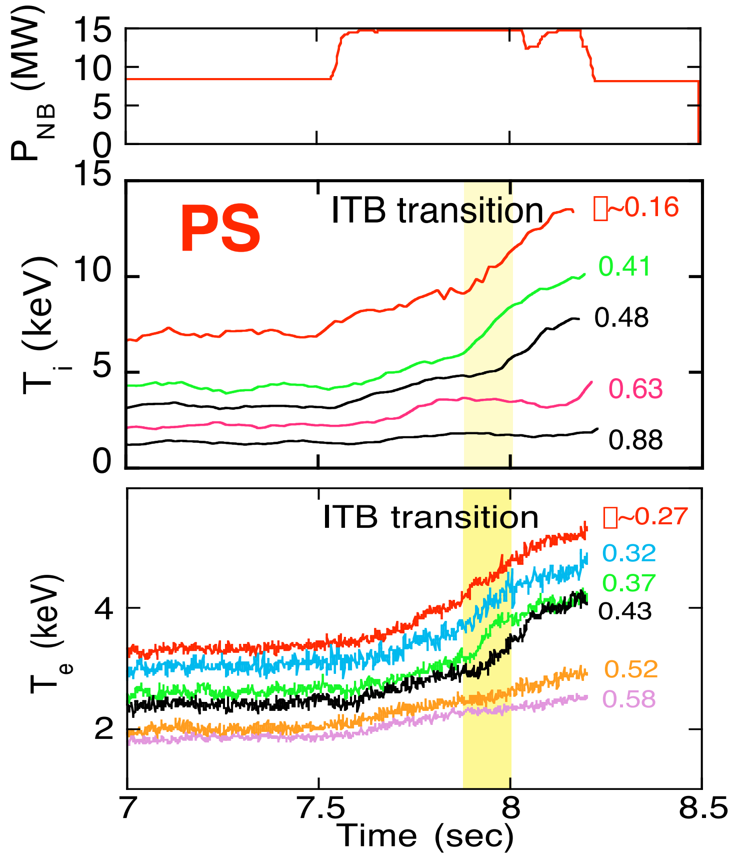
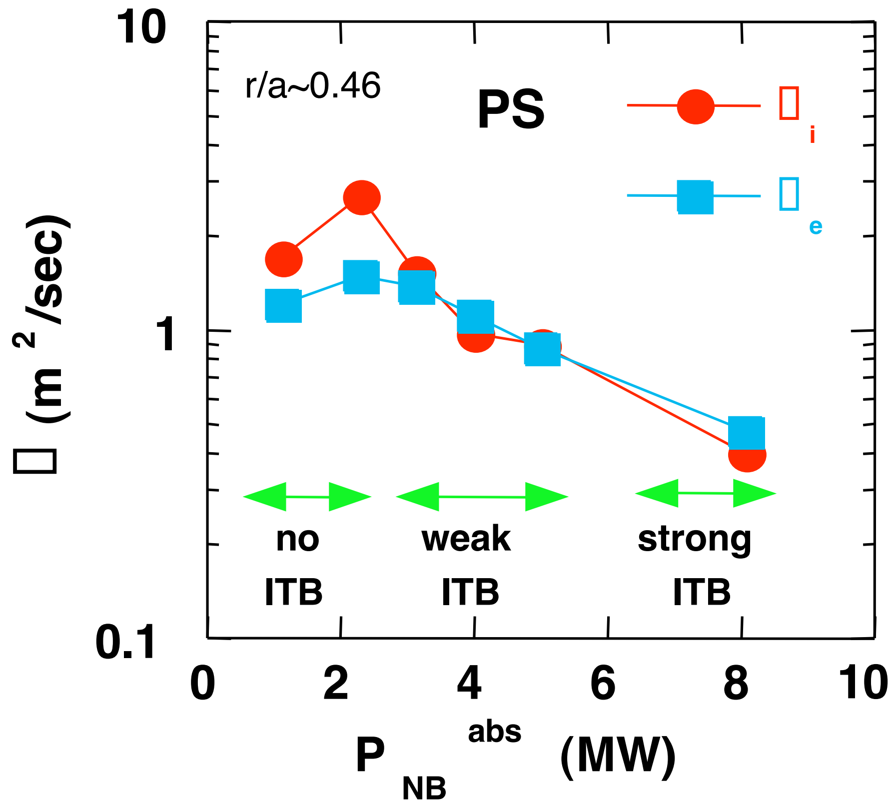
- **Formation of strong T_e ITB requires strong T_i ITB in PS plasma with high power P-NB heating.**
- **Electron heat transport strongly correlates with ion heat transport.**

⇨ **Sustainment of T_i ITB under electron heating is important.**





High confinement is obtained with $T_e > T_i$ in RS plasma.

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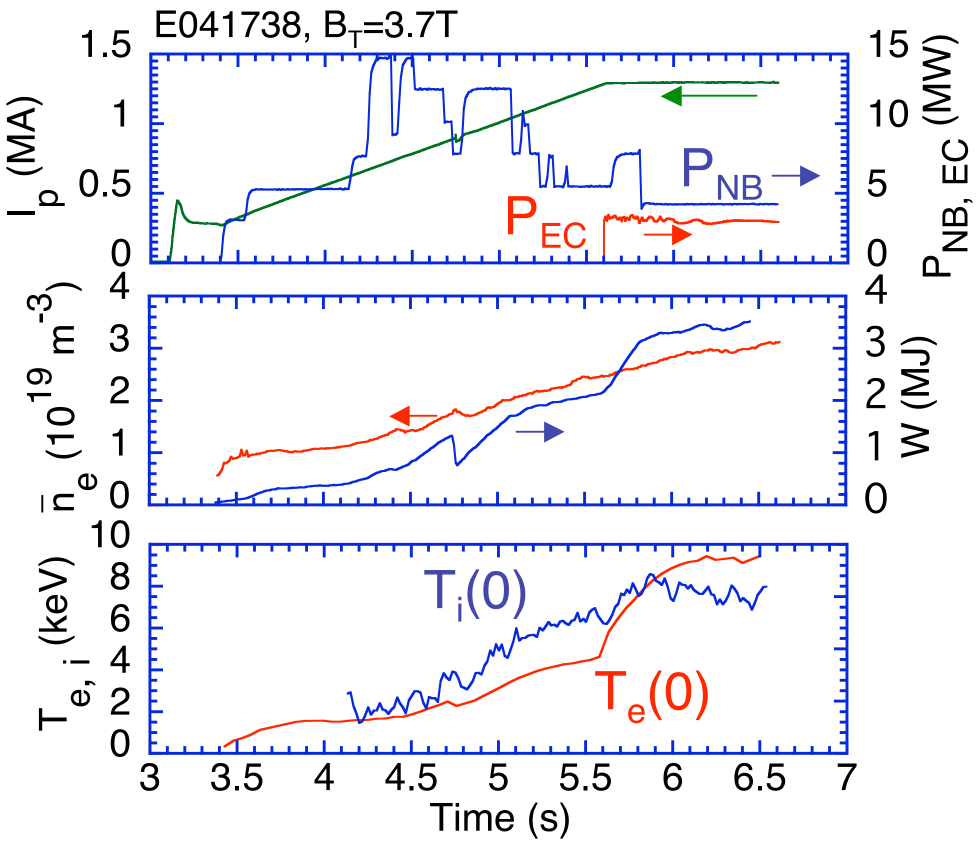
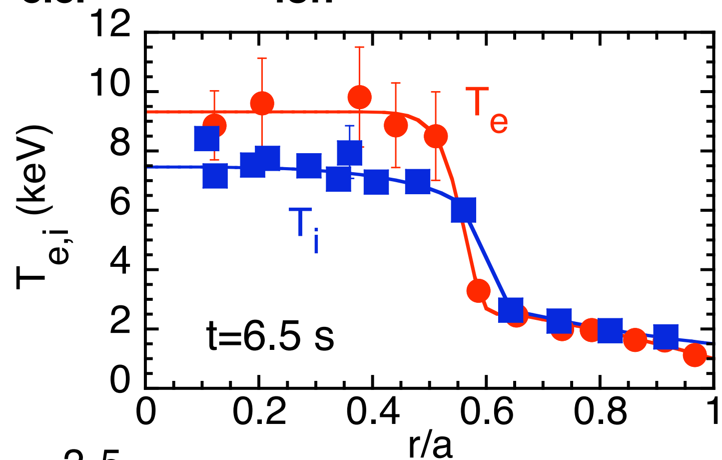
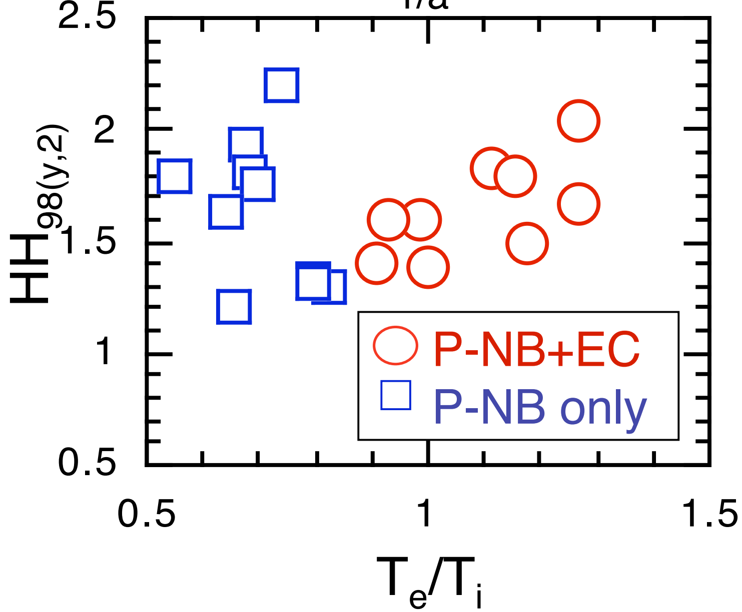
- In RS plasma, strong T_i and T_e ITBs are maintained under dominant electron heating ($P_{ele.} \sim 1.6 \times P_{ion}$).
- $HH_{y2} \sim 2$ is achieved with $T_e > T_i$.



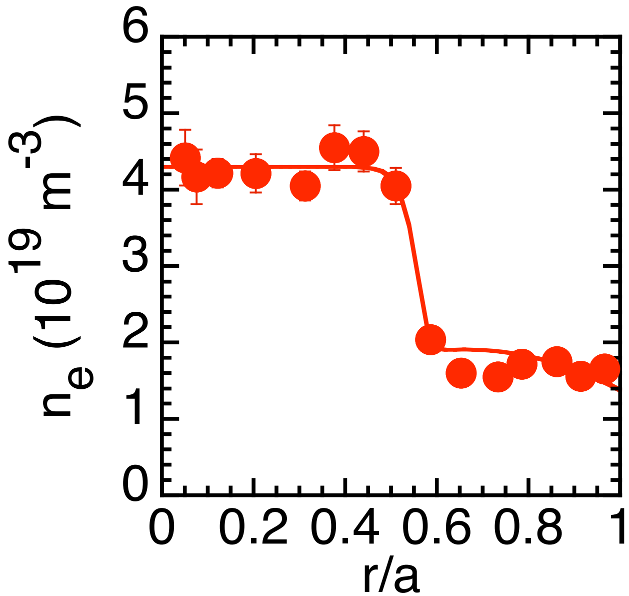




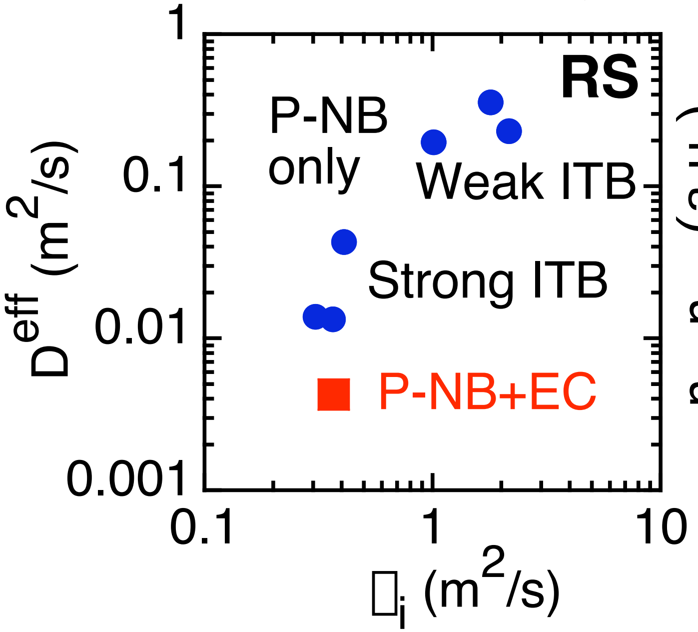
Strong n_e ITB is kept and Ar is accumulated even with small central fueling in RS plasma

JT-60U

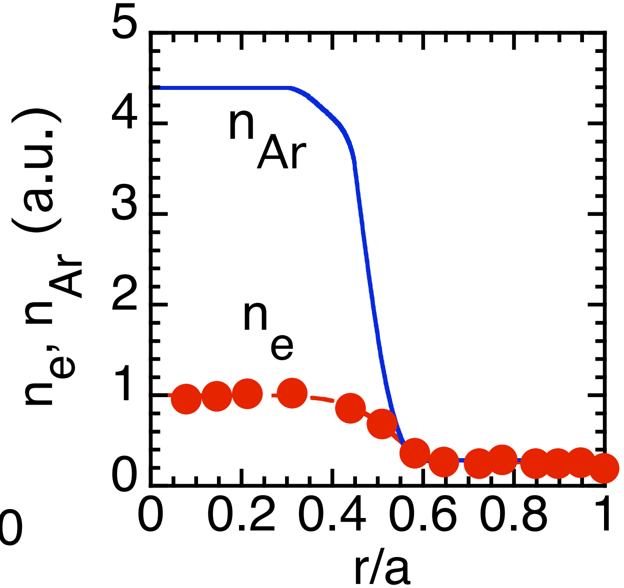
- **A flat density profile is favorable for suppression of impurity accumulation due to small neoclassical inward pinch velocity.**
- **In RS plasma, strong n_e ITB is maintained even with small central fuelling and D^{eff} is smaller with small central fuelling.**
- **Ar is accumulated inside the ITB even with small central fueling, although Ar accumulation is weaker than neoclassical prediction.**



$$\square = \square D^{eff} \square n_e$$



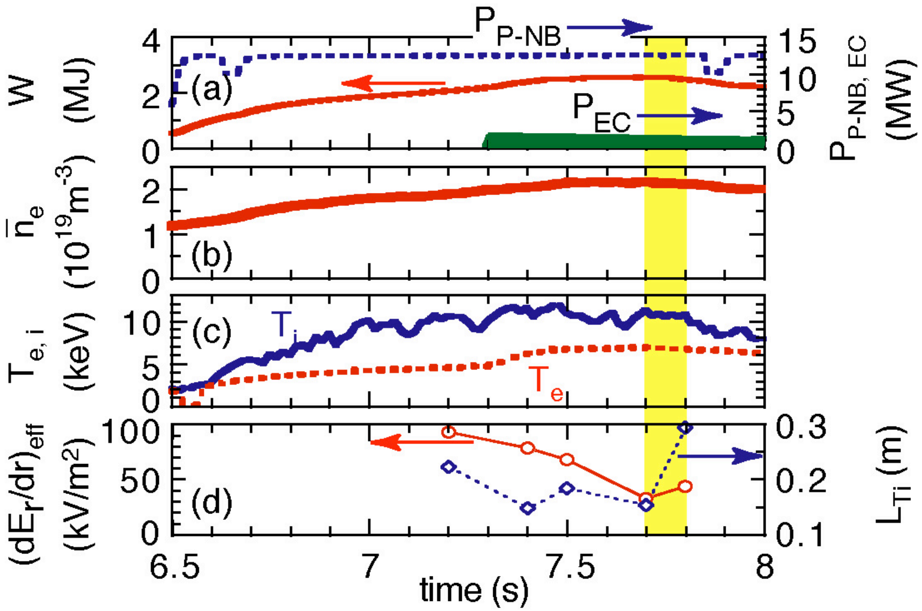
$D_{Ar} \sim 4 \times D_{Ar}^{NC}$ (in ITB)
$v_{Ar} = v_{Ar}^{NC}$



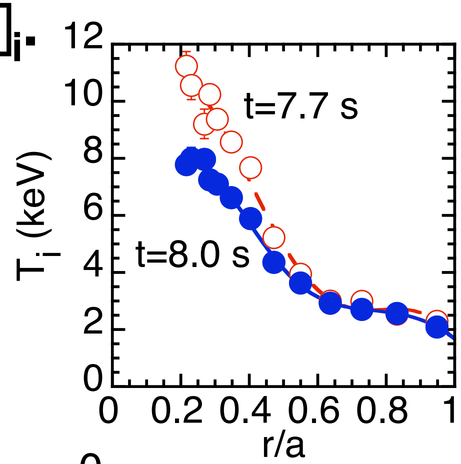
T_i ITB degrades by injecting ECRF in PS plasma

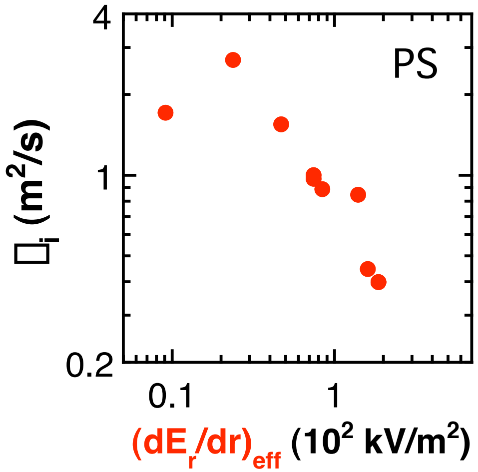
JT-60U

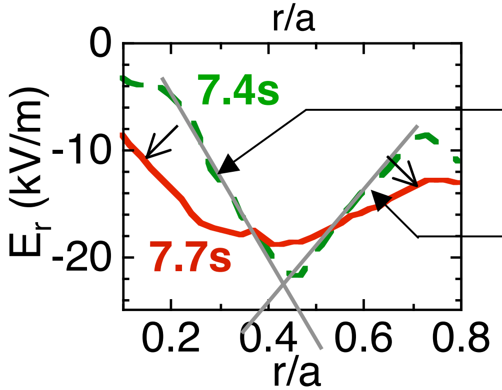
- **Toroidal rotation is flattened and decrease of E_r shear followed by degradation of T_i ITB is observed.**
- **Remarkable correlation between effective E_r shear and χ_i is observed.**
- **The T_i ITB degradation is consistent with the correlation between effective E_r shear and χ_i.**



$$\left(\frac{dE_r}{dr}\right)_{eff} = \left(\left|\left(\frac{dE_r}{dr}\right)_{max}\right| + \left|\left(\frac{dE_r}{dr}\right)_{min}\right|\right)/2$$



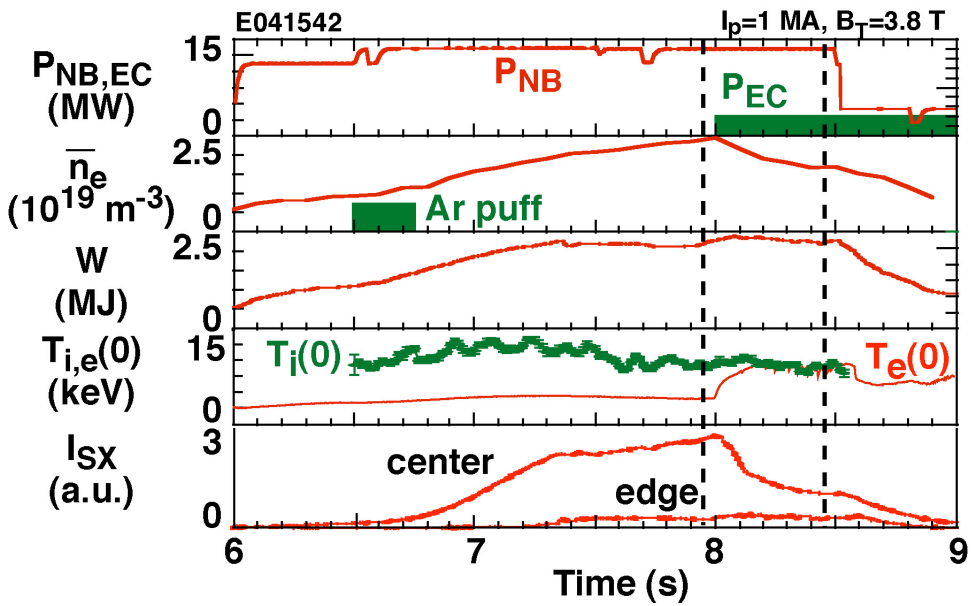


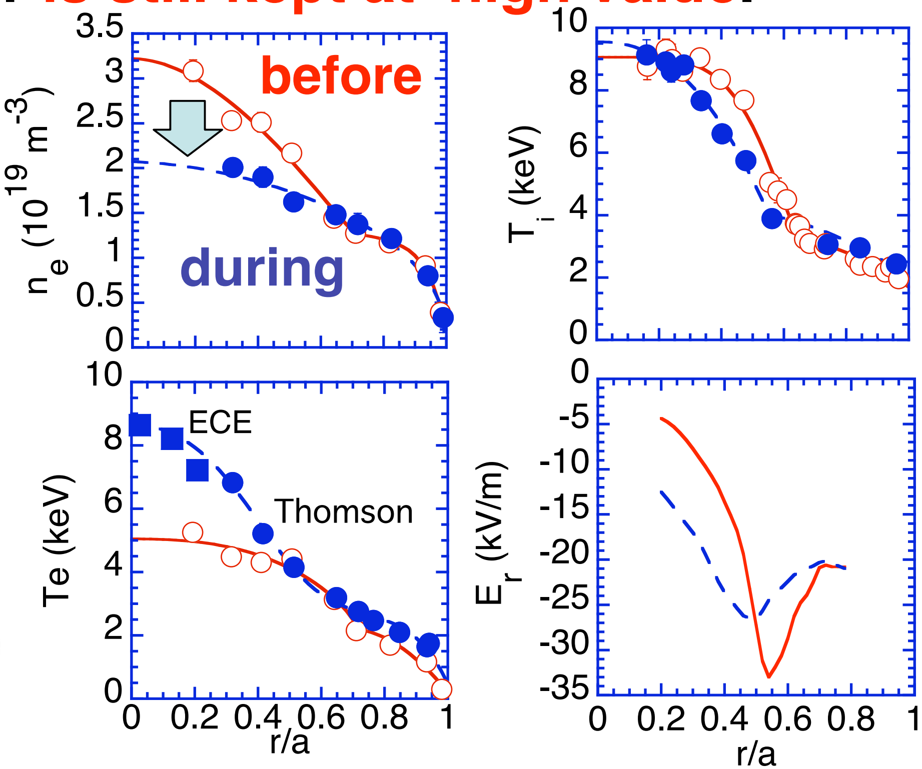


Density profile is flattened by injecting ECRF in PS plasma with Ar puffing

JT-60U

- Large decrease of n_e is observed with small amount of Ar puffing in PS plasma.
- Density and central soft x-ray signal are drastically reduced by injecting ECRF.
- n_e ITB is almost lost, but T_i ITB is sustained.
- E_r shear also reduced, however is still kept at high value.

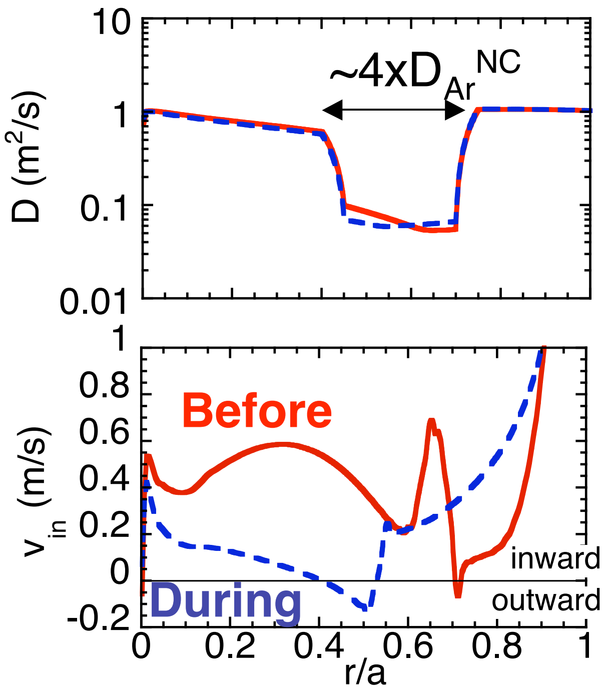




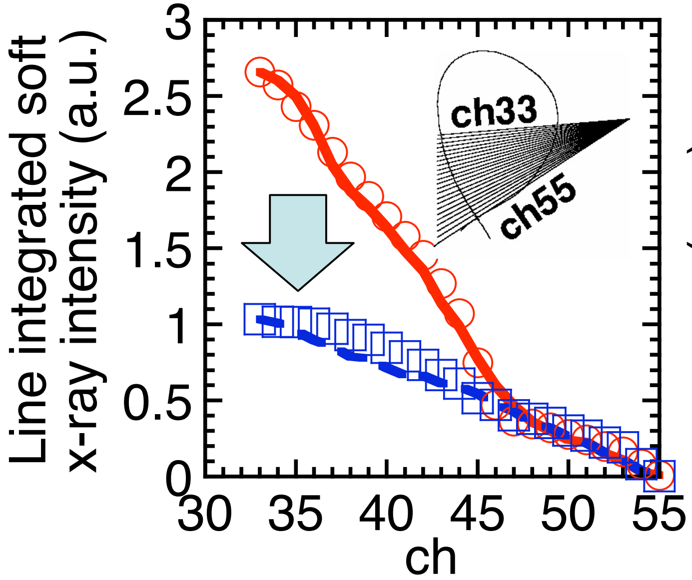
Ar is exhausted from the inside of the ITB.

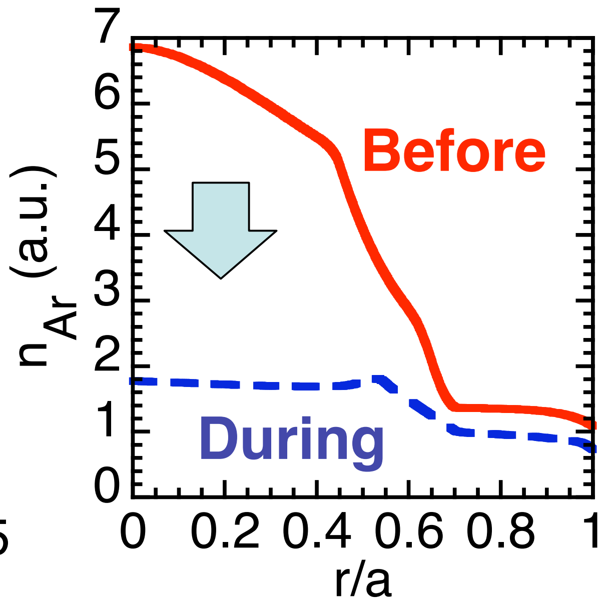
JT-60U

- n_{Ar} profile estimated from soft X-ray profile is more peaked by a factor of 1.6 than n_e profile before ECRF injection and similar as n_e profile during ECRF injection in PS plasma.
- The reduction of n_{Ar} is consistent with the reduction of v_{Ar}^{NC} due to the reduction of n_e gradient
- D_{Ar} is higher by a factor of 4 than D_{Ar}^{NC} in the ITB region.



- Effects of Ar puffing on the flattening of the n_e profile should be investigated in a future work.





Summary

JT-60U

- ITB transport is investigated under **dominant electron heating** and **small central fueling** by using **ECRF system**.

	Reversed shear	Weak positive shear
T_e ITB formation	•Strong T_e ITB without T_i ITB (P_{EC}~1MW)	•No strong T_e ITB without T_i ITB (P_{EC}<3MW)
Sustainment/ degradation of ITB and confinement	•Sustainment of strong ITBs ($T_{i,e}$, n_e) •High confinement of HH_{y2}~2 with T_e/T_i>1	•T_i ITB degradation •Flattening of n_e profile and sustainment of T_i ITB with Ar puff
Heavy impurity accumulation	•Ar accumulation	•Ar exhaust from the inside of the ITB with flattening of n_e profile

- Further study is necessary with N-NB : Are the effects observed in PS plasma intrinsic to ECRF injection or electron heating ?

Main objectives in JT-60U 2003-4 experiment campaign

JT-60U

- **Long sustainment (~30-60 s) of high performance plasmas for >τ_R and ~τ_{wall}**

  Extension of operation pulse length (15 s -> 65 s)

  NB power : 14 MWx30s

  RF power : ~2 MWx60s

- **Sustainment of high β_N (3-3.5) by stabilizing NTM**

- **Extension to high density towards highly integrated performance**